IEEE 802.21 Transport Solution Using Cross-Layer Optimized Stream Control Transmission Protocol

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Abstract—**The Media Independent Handover (MIH) architecture is designed to facilitate the signaling and enable seamless handovers in heterogeneous networks. In this paper, we propose a solution using the Stream Control Transmission Protocol (SCTP) to efficiently carry MIH messages. The solution uses SCTP's multihoming and multistreaming capabilities along with cross-layer information available through the MIH. We analyze the performance of the proposed solution for various packet loss conditions.**

I. INTRODUCTION

Mobile users currently have access to a wide range of wireless technologies. To facilitate handover signaling across heterogeneous networks, the Institute of Electrical and Electronics Engineers (IEEE) 802.21 Working Group is developing a Media Independent Handover (MIH) framework [7]. This framework facilitates the exchange of information across different entities of the mobility management protocol stack within a node and between different network entities via the MIH protocol. The MIH Function (MIHF) is the core element of the MIH architecture and provides three services to its users. The Media Independent Event Service (MIES) generates and distributes layer 1 and layer 2 events in a generic format. The Media Independent Command Service (MICS) allows an MIH user to control the behavior of lower layers. Finally, the Media Independent Information Service (MIIS) enables MIH nodes to collect information about surrounding networks via the current connection.

MIHFs communicate via the MIH protocol. The actual transport mechanism is not specified but the MIH messages can be carried over layer 2, layer 3, or any layer above. The low packet latency and reliability dictate the selection of the transport protocol. If the necessary signaling is not completed prior to losing connectivity, the mobile node relies solely on local information and may connect to an invalid network. The main reason to trigger a handover is a degredation in signal quality. This also means that the connection is suffering from higher packet loss. Thus the transport protocol carrying the MIH messages must be able to maintain its service under conditions of high packet loss.

Traditional transport protocols, namely User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) provide communication between two Internet Protocol (IP) addresses and rely on additional mechanisms such as Mobile IP to handle mobility. This means that the performance of these protocols is dependant on the mobility protocol located at the network layer. In contrast, SCTP [4] embeds multihoming and multistreaming capabilities. The Dynamic Address Reconfiguration [6] also allows SCTP to perform layer 4 handovers. Due to those capabilities, SCTP is an adequate transport protocol for MIH messages. However, the default retransmission mechanism and movement detection need to be optimized by using the MIH services. Therefore, in this paper we propose a transport solution for MIH messages using SCTP that combines an interface selection algorithm, cross-layer optimizations, and enhanced control of SCTP by the MIHF.

The rest of this paper is organized as follows. In section II we present the solution to transport MIH messages via SCTP while using the MIH services to optimize the behavior of SCTP. Section III provides numerical results demonstrating the performance of the proposed solution for various packet loss conditions. Conclusions are given in section IV.

II. PROPOSED TRANSPORT SOLUTION

In this section, we present a solution optimizing SCTP to efficiently carry MIH messages. As shown in Figure 1 there are two views to the proposed solution. In the Mobility Control Plane, SCTP uses MIH services such as events and commands to be aware of changes at the lower layers therefore SCTP is located above the MIHF. In the data plane, MIHF sends and receives MIH messages by using SCTP as a transport protocol, thus MIHF is located above SCTP.

There are three main components to the proposed so-

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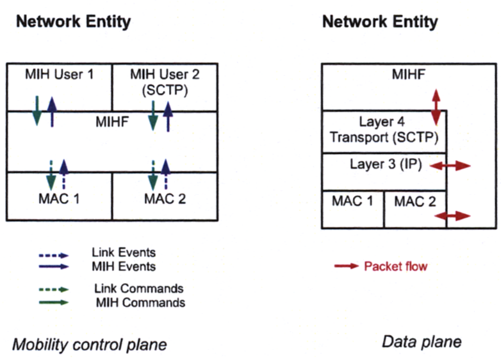


Fig. 1. MIH architecture

lution: an interface selection algorithm for SCTP, fast movement detection using the MIH services, and the control of SCTP by the MIHF to reduce the time spent sending expired information.

A. Interface selection algorithm

In this subsection, we present the algorithm used by SCTP to determine the best interface to use for communication. SCTP allows end points to communicate via multiple addresses. When packets are lost on the primary path, SCTP uses an alternate destination address for retransmissions. Performance of multihoming has been studied in [2] and [3] and results show reduced packet latencies when packet loss occurs. Nevertheless, the performance of multihoming still relies on the selection of the primary path. We propose to use an algorithm to estimate the average delay to transmit a packet using one interface including one retransmission on another interface. Let RTT_i be the measured Round Trip Time using interface i. Let RTO_i be the current value of the retransmission timer for chunks sent via interface i. Finally, let L_i be the current packet loss measured on interface i.

The RTT and RTO are measurements already available within SCTP. The MICS is used to retrieve the current packet loss at the interface.

If the transmission succeeds using interface i, with a probability $1 - L_i$, the delay is RTT_i. If the first transmission fails, with a probability L_i, and succeeds when retransmitting using interface j, with a probability $1 - P_j$, the delay is $RTO_i + RTT_j$. We can deduce the average delay:

$$Delay(i,j) = (1 - L_i) * RTT_i + L_i * (1 - L_j) * (RTO_i + RTT_j) \quad (1)$$

SCTP determines the interface i to use as primary interface and interface j to retransmit that minimizes $Delay(i,j)$.

B. Enabling fast movement detection using MIH services

This subsection describes how SCTP uses the MIH services to optimize its performance. The Dynamic Address Reconfiguration [6] extension enables an SCTP end point to advertise changes about its local addresses. A new chunk type called Address Configuration Change (ASCONF) is used by an end point to add or remove addresses by which it is reachable. It also allows an address to be specified as a primary destination. With this mechanism the remote node does not wait for the longer Heartbeat timer expiration to determine that an address is not reachable.

The default mechanism to indicate if an IP address is valid is provided by the Neighbor Discovery (ND) protocol. When the prefix of the node expires, it indicates that the node is no longer connected to its Access Router (AR). The delays for prefix expirations are in the order of seconds. To detect movement faster, SCTP uses the MIES. Upon receiving the *MIH_LINK_DOWN*, SCTP sends an ASCONF chunk to deregister the interface's address. If the node only has one interface, SCTP will wait until the connection is reestablished to update the peer node. It also interacts with the IP layer to receive indication that a new address has been configured then sends an ASCONF chunk to register the new address.

Furthermore, the proposed solution uses the algorithm presented in section II-A to determine the appropriate primary path. SCTP retrieves the current packet loss using the MICS. If the best interface is different after running the algorithm, SCTP sends an ASCONF chunk to update the primary path.

C. MIHF control of SCTP

In this section, we describe how an MIHF can control the SCTP's configuration and further improve the transmission of MIH messages. An SCTP-aware application can control the number of streams and the addresses to advertise during initialization. The MIH services are independent of each other, have different constraints, and may be provided by different Points of Service (PoSs). Therefore, when an MIHF creates an association with a PoS, it will only create streams for the supported services. Allowing each MIH service to operate on a different stream reduces message blocking due to retransmission.

Applications can also specify the packet lifetime, ordering, and context identifier for each message sent.

SCTP Partial Reliability (PR-SCTP) [5] extension provides mechanisms to skip the transmission of a given data chunk. PR-SCTP applies the packet lifetime to both queued messages and transmitted chunks not yet acknowledged. If the lifetime expires, the sender informs the receiver that the chunk must be skipped. The problem is that the lifetime parameter used by PR-SCTP is passed when sending a message. This assumes the application has knowledge of the message validity prior to sending. If we take the example of MIH Events, the information reported is valid as long as a new event does not invalidate it. The proposed solution assumes that the SCTP protocol provides a new function to allow the application to cancel the transmission of a message after it is sent to SCTP. This function only requires the context identifier as parameter. We then propose to have the MIHF maintain information about the events sent to SCTP and indicate when they are no longer valid. The solution is based on event priority as shown in Table I. In this table, a lower priority value indicates a higher priority. We distinguish four types of events: Link State events indicate a change in the state of the interface; Link Synchronous events indicate that the lower layer is starting or has completed a handover; The Link Prediction events indicate the link may go down or that the prediction is no longer true; Finally, the Link Parameters events indicate changes in network conditions.

Table I also shows the maximum number of pending events in each category. We allow having multiple pending Parameters change events due to the fact that each event may contain different, and sometimes multiple, parameters.

The MIHF maintains the list of events for each link. The following algorithm is used to decide when the MIHF informs SCTP that a message is no longer valid:

1) *When a new message must be sent, look up its priority*
2) *Cancel all messages that have lower priorities*
3) *If the multiplicity is 1, then cancel the message from the same category; otherwise if there are already N messages in the sending list, cancel the oldest event in the list.*

We note that SCTP may have successfully transmitted the messages that the MIHF is indicating as expired and will just ignore the command.

TABLE I
PRIORITY AND MAXIMUM NUMBER OF PENDING MIH EVENTS

MIH Event type	Maximum number of pending events	Priority
Synchronous	1	1
State	1	1
Prediction	1	2
Parameters change	N	3

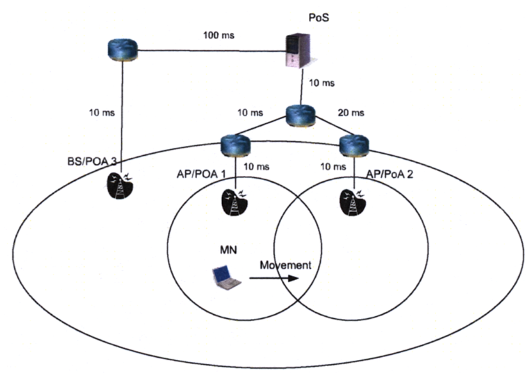


Fig. 2. Simulation topology

III. PERFORMANCE EVALUATION

To evaluate the performance of the proposed solution, we extended the mobility framework for NS-2 [1]. The extension includes the implementation of PR-SCTP, Dynamic Address Reconfiguration and the integration with the MIH framework. This section presents the scenario used and the simulation results.

A. Scenarios

The topology and network configuration used to perform the evaluation are shown respectively in Figure 2 and Table II. An MN is connected to an 802.11 Access Network (AN) and is moving at constant speed away from its Access Point (AP). When the measured signal strength decreases below a pre-configured threshold, the lower layer periodically generates LINK_Going_Down events along with parameter reports. When the MN is multihomed, it will also be connected via a second interface to an 802.16 AN. We control the packet loss on the 802.11 link and vary it from 0 % to 40 %.

We analyze the performance of the proposed solution for MN initiated and Network initiated handovers. The message flows are shown in Figure 3. For MN initiated handover, the reception of a local MIH_Link_Going_Down triggers a scanning to find protential target AN. Then the MN communicates with the PoS via MIH_MN_HO_Candidate_Query request/response to obtain information about potential target networks. Upon receiving the response, the MN decides which target AP to use and informs the PoS via MIH_MN_HO_Commit request. When the PoS acknowledges the request,

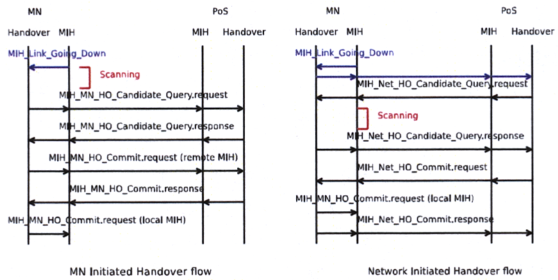


Fig. 3. Message flow during handover

TABLE II
GENERIC SIMULATION PARAMETERS

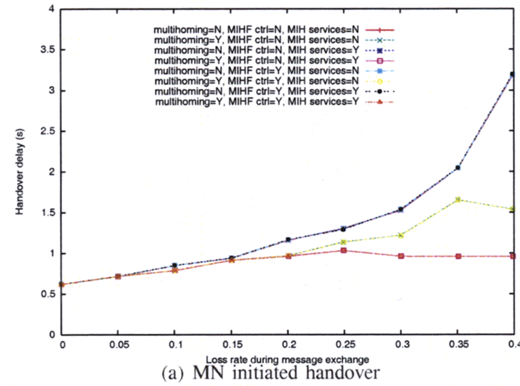
Parameter	Value used
Network topology	
WLAN cell coverage	disk with a radius = 50 m
WIMAX cell coverage	disk with a radius = 500 m
802.11 MAC Sublayer Configuration	
Data rate (Mb/s) Default scanning mode Default propagation model Packet loss	11 Active TwoRayGround 0-40 %
802.16 MAC Sublayer Configuration	
Default scanning mode Default propagation model Packet loss	Active TwoRayGround 0 %
Mobility Model	
Velocity (m/s) Path	1 Straight line
SCTP Configuration	
Segment size (bytes) Default number of streams	1448 1
Event configuration	
Event rate interval (s)	0.15

the handover is executed. In the case of Network initiated handover, the MN first sends a remote MIH_Link_Going_ Down to the PoS. The PoS tells the MN to search for potential targets via the MIH_Net_Candidate_Query requests, triggering a scan. The result of the scan is reported to the PoS, which performs the target selection. The decision is transmitted to the MN via an MIH_Net_HO_Commit request. When receiving the request, the MN performs the handover and sends a confirmation to the PoS.

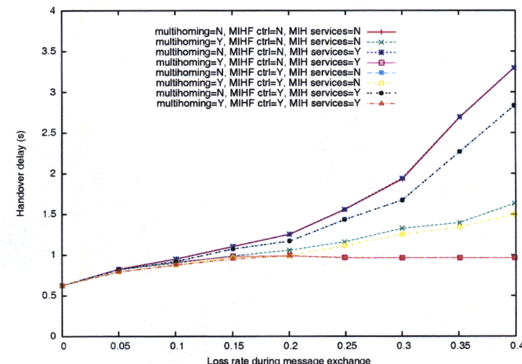
We study the impact of packet loss on different MN's capabilities, namely multihoming, use of MIH services, and the control of SCTP by the MIHF.

B. Numerical results

The results in this section show the mean handover delays and handover delay distribution of the proposed



(a) MN initiated handover



(b) Network initiated handover

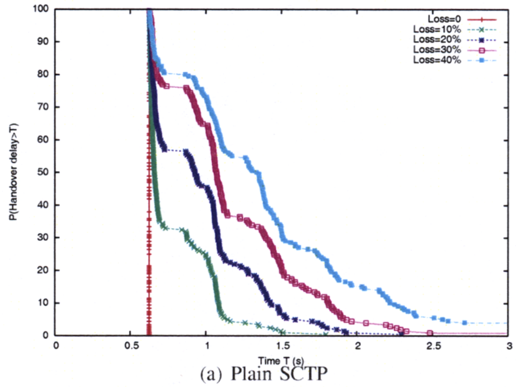
Fig. 4. Impact of the packet loss on the handover delay

solution to carry MIH messages for different packet loss conditions.

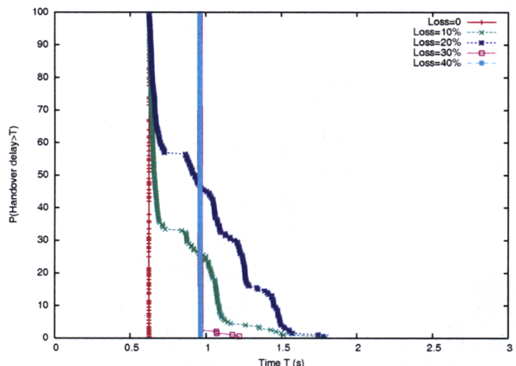
1) Mean handover delay analysis: The results in Figures 4(a) and 4(b) show the average handover delays for the MN and Network initiated handovers respectively.

Influence of the multihoming capability: The highest delays occur when the MN has only one interface. For 40 % packet loss we measure delays up to 3.2 s for both MN and Network initiated handovers. When the MN is multihomed the handover delays are decreased. When MIH services are not used, SCTP uses the second interface for retransmission but does not change the primary path. We observe delays up to 1.6 s when the primary connection suffers from 35 % of packet loss. On the other hand, if MIH Services are used, the adequate path is computed according to the algorithm described in section II-A. This leads to delays up to 1 s in both MN and Network initiated handovers.

Influence of using MIH services: The results confirm that cross-layer optimization does not provide better performance when the MN is not multihomed. Even though the connection is weak, retransmissions must



(a) Plain SCTP



(b) Proposed solution

Fig. 5. Handover delay distribution for various packet loss in MN initiated handovers

occur on the same interface. We notice that if the packet loss is less than 15 %, all solutions perform the same with delays between 0.6 s and 1 s. This is because using the 802.11 interface still provides better results than changing the primary path to the 802.16 interface. Beyond 15 %, the interface selection algorithm estimates it is beneficial to change the path.

Influence of MIHF controlling SCTP: In the case of MN initiated handovers there are only commands sent (no remote events). The results are identical whether the MIHF controls SCTP or not, thus the curves overlap. For Network Initiated handovers, we can see that if the MIHF indicates when events are outdated, the delays are reduced by up to 20 %. This is especially true when the MN only has one interface. If the MN is multihomed, the impact is less due to already lower transmission delays.

2) Handover delay distribution: Figure 5(a) and Figure 5(b) show the distribution of the delay to complete an MN initiated handover respectively for a plain SCTP implementation and for an implementation using the proposed solution when the MN is multihomed. We notice that in Figure 5(a) the delays are highly impacted by packet loss. For 10 % packet loss, there is a 25 % probability that the handover exceeds 1 s while for 40 % packet loss, the probability that the handover delays take more than 1 s is 75 %. On the other hand, when SCTP uses the proposed solution, the delays become less sensitive to packet loss. The probability that the handover delays exceed 1.0 s is less than 50 % regardless of packet loss. We observed similar results for Network initiated handovers.

The results show that by enhancing SCTP's capabilities with an interface selection algorithm, cross-layer information, and MIHF support we can reduce the impact of packet loss on handover delays.

IV. Conclusion

In this paper, we presented the MIH framework that provides seamless handovers in heterogeneous environment when an MN is capable of connecting to multiple ANs via multiple interfaces. The delay to exchange MIH messages is critical to achieving fast handover. We also introduced SCTP and its capabilities such as multihoming, multistreaming, partial reliability, and address reconfiguration. We then proposed a complete solution to use SCTP as an efficient transport solution for MIH. The solution combines a path selection algorithm and the use of MIH services to optimize SCTP's behavior. It also extends the Partial Reliability feature to allow the MIHF to indicate when a message is no longer valid. Simulation results show that the proposed solution reduces the impact of the packet loss on the transmission delays. Future work will analyze the impact of multiple events generation on handover delays.

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